Analyzing the Dependence between RADARSAT-1 Vessel Detection and Vessel Heading using a CFAR Algorithm for Use in Fishery Management

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***Abstract*-The National Oceanic and Atmospheric Administration (NOAA) National Environmental Satellite, Data, and Information Service (NESDIS) provides Synthetic Aperture Radar (SAR) derived products under a demonstration project named the Alaska SAR Demonstration (AKDEMO) to the US government community. The AKDEMO near real-time data and products include SAR wind images and vectors, hard target locations, and ancillary data. The hard target locations are available for use in fishery management by agencies such as the Alaska Department of Fish and Game (ADF&G), the National Marine Fisheries Service (NMFS) and the United States Coast Guard (USCG). Vessel positions are obtained from hard target signatures through the use of a constant false alarm rate (CFAR) vessel detection algorithm developed by Veridian Systems Division. This algorithm has gone through testing and validation, using fleet information and vessel observer reports, during Red King Crab fisheries in Alaska in 1999 and 2000. The goal was to maximize the number of ships found while minimizing the number or false alarms. Using general fleet location information, it was found that the minimum vessel size detected by the CFAR algorithm was 36 m using RADARSAT-1 ScanSAR Wide mode data with a nominal spatial resolution of 100 m. Still, when comparing the CFAR results with the actual positions reported by the ship observers, vessels over 36 m were not always detected. This led to the hypothesis that the heading and perhaps wind conditions may have affected the ability of SAR to detect the vessels. In 2001, vessel observers again reported their positions during SAR overpasses, this time also reporting heading and wind conditions. Unfortunately, due to high winds and waves, SAR was not able to detect the fishing fleet. In 2002, this was repeated, resulting in 3 days during the fishery opening when RADARSAT-1 was able to image the fishing fleet in the ScanSAR wide B mode. Approximately twenty ships each day in the area covered by RADARSAT-1 data reported their position and heading. Results showing the dependence between RADARSAT-1 vessel detection and vessel heading will be presented using a GIS platform.**

I. INTRODUCTION

The United States exclusive economic zone (EEZ), which extends 200 miles from land, covers approximately 4.5 million square miles. The EEZ is 25% larger than the land mass of the U.S. and poses a great challenge to monitor. With new homeland security issues for the U.S. since September 11, 2001, the government has also had to shift resources away from this task. A recent study done by the General Accounting Office (GAO) found that the U.S. Coast Guard's fisheries enforcement duties have declined by 38% due to the need to shift their resources towards homeland security [1]. A large portion of the EEZ is in Alaska. The fisheries in this area are managed by the Coast Guard, the Alaska Department of Fish and Game (ADF&G), and the National Marine Fisheries Service (NMFS) in part with aircraft and ship surveillance, vessel monitoring systems, and vessel observer programs.

Satellite data is being tested as another tool to use in the management of fisheries. Satellites can monitor large portions of the EEZ and possibly can be used to target the regions where the management agencies should be using their resources. A particularly good type of data for vessel detection is synthetic aperture radar (SAR). For almost four years, the National Oceanic and Atmospheric Administration (NOAA)/National Environmental Satellite, Data, and Information Service (NESDIS) has been providing ship position information to these agencies. This information is automatically generated by a Constant False Alarm Rate (CFAR) vessel detection algorithm developed by Veridian Systems Division [2] under the context of a pre-operational system called the Alaska SAR Demonstration (AKDEMO) at NOAA/NESDIS [3]. SAR data is taken daily over the Bering Sea and Gulf of Alaska and processed through the CFAR algorithm to produce vessel positions. The product is an ASCII list

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of detected targets and their locations. This, along with other data sets and derived products, is distributed to users through a password protected web interface. Starting in 2003, mapped vessel positions will be internally produced in ARCGIS shape file format.

Past work has been done to find the appropriate threshold for vessel detection using the Veridian Systems Division CFAR algorithm [2][4][5]. The results from these studies used either general fleet descriptions and/or *in situ* data from Alaska Department of Fish & Game (ADF&G) observer vessels participating in the Bristol Bay Red King Crab Fishery. The Bristol Bay Red King Crab Fishery is in the eastern Bering Sea and is the largest red king crab fishery in Alaska. The fishery area, shown in Fig. 1, is bounded on the north by 58deg 39' N lat, on the south by 54deg 36' N lat, and on the west by 168 deg W. 244 vessels pre-registered for the 2002 fishery which opened at 4:00 PM Alaska Standard Time (AST) on October 15 and closed at 12:00 noon, October 18. By the end of the fishery, approximately 8.5 million pounds of red king crab were collected. The Alaska Board of Fisheries allows for the placement of observers on catcher vessels [6]. Approximately 10 percent of the vessels in this fishery included observers, and these observers were asked to record *in situ* data at the time of three RADARSAT-1 passes covering the fishery during the time the fishery was open. These data are compared to the results of the CFAR algorithm to measure the algorithm's effectiveness at detecting ships with different headings and in different wind and sea conditions.

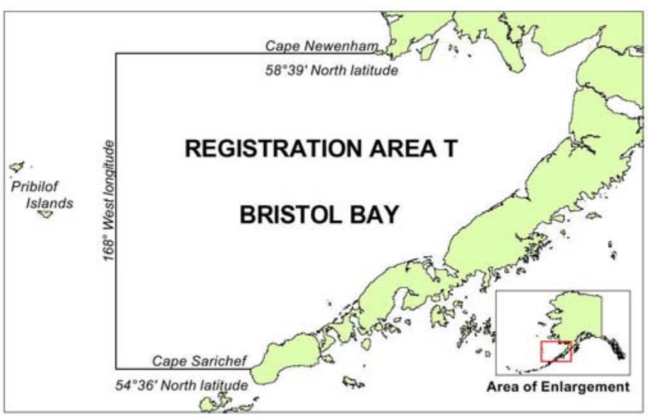

Fig. 1 Map of Bristol Bay Red King Crab Fishery [6].

II. DATA

The SAR data used in this study is from the Canadian RADARSAT-1 satellite, which was launched in November 1995 into a sun-synchronous polar orbit with an ascending equator crossing time (local time) of 6:00 p.m. It has a 5.6 cm C-band SAR with HH polarization. RADARSAT-1 has the ability to revisit a spot within the Bering Sea region, at approximately 60 degrees latitude, every 1 to 2 days. The sensor mode used in this study is ScanSAR Wide B with a swath width of 480 km. The Alaska SAR Facility (ASF) in Fairbanks, Alaska, receives data within the Alaska station mask directly from the satellite. They in turn provide SAR data in near real-time (within approximately 4 hours) to users through the NOAA Satellite Active Archive (SAA) in a reduced resolution format called quicklook, which also uses predicted state vectors. Quicklook Scansar Wide B data has a resolution of 200 m, as opposed to full resolution data with a resolution of 100 m using restituted state vectors. The AKDEMO workstation then processes the SAR data with the Veridian Systems Division CFAR algorithm, producing both an ASCII file with a list of ship locations and a graphic of the SAR image with ship locations overlaid, within approximately 10 minutes. Recently NOAA/NESDIS started converting the ship positions into ARCGIS shape files.

III. VESSEL DETECTION ALGORITHM

The vessel detection algorithm works by locating regions of bright image samples that are statistically different from the surrounding ocean clutter [2]. This procedure is often referred to as a constant false alarm rate (CFAR) process since it is a relative measure based on the local statistics of the background clutter and thus keeps the number of false alarms constant as the mean of the clutter varies. It uses a local window with a size based on the image's resolution for a signal box that is assumed to contain a ship, a buffer window that contains the signal window, and a background window that contains the buffer window (and thus also the signal window). These windows are moved through the image as a set, shifting by one image sample each time. At each position, the mean image value within the signal box is calculated, m_s, as well as the mean and standard deviation of the image values within the background box but not within the buffer box (m_b and σ_b respectively). A detection statistic, d, is then calculated as $d = (m_s - m_b)/\sigma_b$. Finally, a threshold, T_o, is applied to d: if $d \geq T_o$ then a ship has been detected within the signal box, if $d < T_o$ then no ship has been detected. More information on the CFAR algorithm can be found in [2].

IV. RESULTS

During the Bristol Bay Red King fishery of 2002, RADARSAT-1 imaged the region three times with ScanSAR wide B data. The first was on October 15 at 9:02 AST when it was imaged with a descending mode pass, the second was on October 15 at 20:30 AST with an ascending mode pass, and the last was on October 18 at 9:15 AST with a descending mode pass. A frame of the data, approximately 480 km by 500 km, does not completely cover the fishery region, but it was able to cover much of the main fleet. Fig. 2 shows a mapped SAR image from October 15 at 9:02 AST where the

fleet is mainly located in the southwest corner of the image (the vessels cannot be seen by the reader at this reduced resolution).

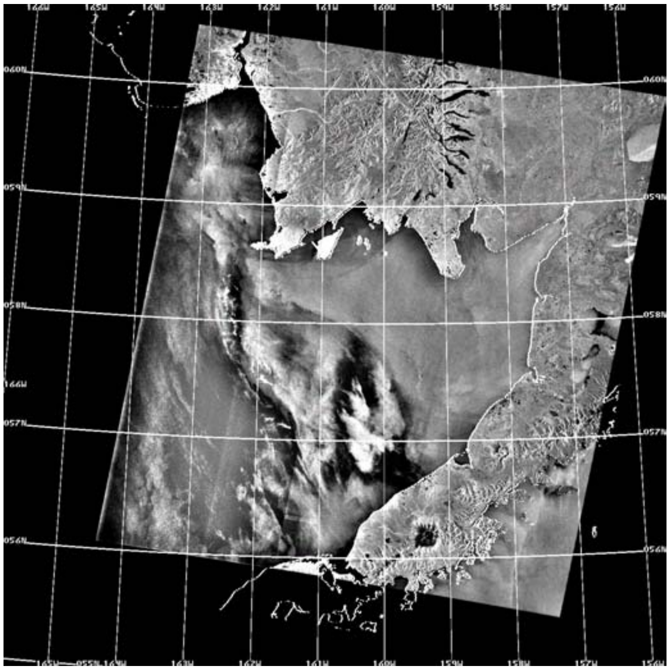

Fig. 2. Reduced resolution mapped SAR image on October 15, 2002, 9:02 AST. © CSA, 2002.

Of the 244 vessels pre-registered for the fishery, approximately 10 percent participated in the Alaska Board of Fisheries observer program. These observers voluntarily recorded their location, the ambient wind speed, their vessel's heading, and the current sea state, at the times of the SAR overpasses. These times were given to them ahead of time, and most of the observations were able to be taken at or near the time of the overpass. Table 1 shows that on the three days respectively, 18, 20 and 16 observers took down the required measurements within 1 hour of the overpass. If observer data over 10 minutes old is thrown out, there are 15, 17, and 11 observations from these respective days to use in this study.

The three days of SAR passes were passed through the CFAR algorithm in two different resolutions. The quicklook data, which is received by NOAA from ASF in near real-time (within 4 hours) has a reduced resolution, 200 m, and is geolocated using predicted state vectors. The higher resolution data is processed using the restituted state vectors and has a resolution of 100 m. NOAA does not receive these data in near real-time, therefore NOAA's AKDEMO program is run using the quicklook data. ASF has only calculated the geolocation error of the high resolution data. This error was found to be 277 meters, with a standard deviation of 135 meters. The high resolution data is not mapped, therefore no error is introduced by mapping. Quicklook data is mapped into polar stereographic projection which may add another level of error. Since only the error of the high resolution data is known, only the detections from this data are compared to the observer reports.

DAY	02288 10/15/02 9:02 AST	02289 10/15/02 20:30 AST	02291 10/18/02 9:15 AST
SHIPS IN BOUNDS W/IN 1 HOUR	18	20	16
SHIPS IN BOUNDS W/IN 10 MIN	15	17	11
SHIPS FOUND BY HIGH RES	5	1	0
AVE WINDS SPEED (m/s) *	4.5	4.5	8.3
AVE SEA STATE (m)*	0.9	0.9	2.1

Table 1. Data from the CFAR detection algorithm and the observers by date. (* uses approximately 13 reports for these measurements)

The SAR data is processed through the CFAR algorithm, and all points detected with a detection threshold of 5.5 and above are output to an ASCII file along with their associated latitude and longitude values. These data and the observer data are then converted into ArcGIS shape files and plotted in ArcGIS (Fig. 3). The data is queried to find all of the observer locations that are within a specified distance from a vessel detected by the CFAR algorithm. The distance we use for the bounds of error, is the position error (277 m) plus two standard deviations (each of 135 m) plus an error possibly introduced by an azimuth shifting (represented 500 m). This comes to approximately 1050 m.

The results for all three RADARSAT-1 scenes are shown in Table 1. The first scene has five matches within the bounds of error, the second scene only one, and the third has none. These results are good for the first scene seeing that only 15 observer ships have reliable information within 10 minutes of overflight. But they are very poor for the other two scenes. As shown in Table 1, the third scene has approximately twice the average ambient wind speed and sea state (i.e. wave height) as the first image. The first and second images are taken during similar conditions, which is not unreasonable since they are only 11 hours apart. Based on the results from the first image and that it is taken during similar conditions, we would expect to find 4-5 more matches in the second image which we did not find.

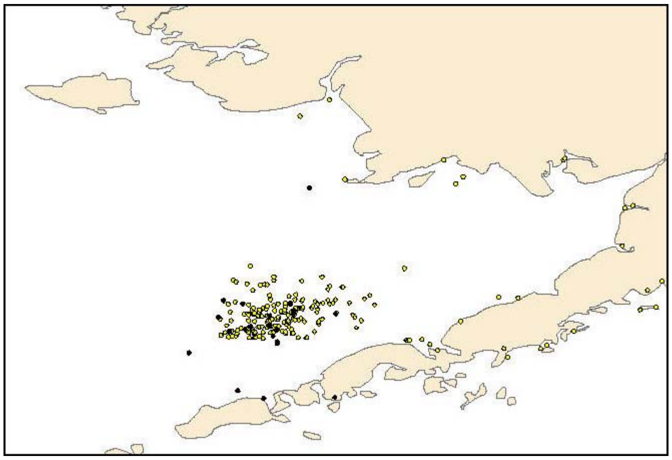

Fig. 3. October 15, 2002, 9:02 AST detections and observer reports mapped in ArcGIS. Black dots are observer vessels, yellow are CFAR high resolution detections.

Another condition that can effect the detection of vessels is the vessel heading. A vessel (assuming it is linear in nature), when aligned parallel to the SAR sensor's look direction would have less chance of detection than a vessel oriented at 90 degrees to the sensor. For RADARSAT-1, the ascending look direction is 98 degrees and the descending is 278 degrees. To see if the rate of detection depended on the heading, the observer vessels were asked to record their heading during the SAR overflight, and most did. For the first image, 4 out of 5 observers on the matching vessels, and the single match on the second image, recorded their heading. Headings for all observer vessels are plotted in Fig. 4. Since the vessel alignment is the same whether the heading is "N" degrees or "N + 180" degrees, the headings have been grouped in groups of 30 degrees from 0 to 180 and then combined with the corresponding group in the 180-360 range.

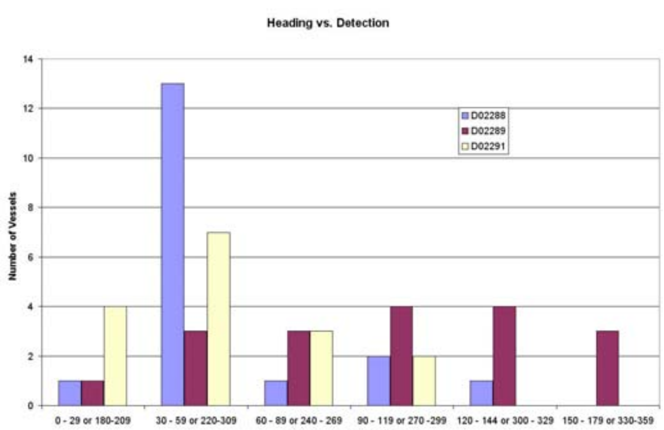

Fig. 4. Headings on 02288 (10/15/02 9:02 AST), 02289 (10/15/02 20:30 AST) and 02291 (10/18/02 9:15 AST) in 30 degree groups.

Since the first and second scene are the only two with any matches between the observer vessel and CFAR detected vessel, and they are taken during similar wind and wave conditions, their heading information has been combined to produce Fig. 5. This information is also displayed in another graph in Fig. 6. They both show that all matches occur in the 0 to 60 degree and 120 to 150 degree ranges (and their corresponding angles after adding 180 degrees). Of notable absence are any detections from 60 to 120 degrees (and 240 to 300), which is what would be expected since the SAR sensor's look direction is 278 degrees in the first image and 98 degrees in the second image. But Fig. 5 and 6 represents only 5r matches, and therefore this is not a robust result. More studies need to be done resulting in many more matches before a conclusion can truly be drawn relating vessel detection and heading.

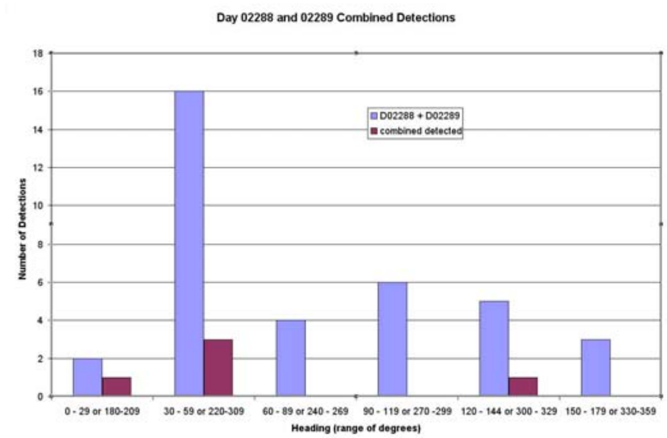

Fig. 5. Combined headings on 02288 and 02289 (10/15/02 9:02 AST and 20:30 AST) of all observer vessels (blue), and matched observer vessels (red).

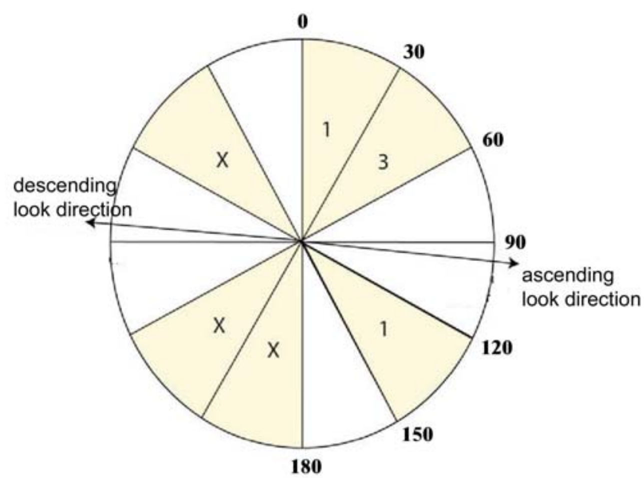

Fig. 6. Observer vessel positions that match the CFAR algorithm positions are plotted by angle. The number inside of the shaded regions represent either the number of matches in this range, or that range plus 180 degrees (represented with an X).

V. CONCLUSIONS

When comparing the observer reports from the 2002 Bristol Bay Red King Crab fishery to results from an automatic CFAR vessel detection algorithm using RADARSAT-1 data, some relationship between detection and wind/sea conditions, and between heading may have been found. All detections were found in the 0 to 60 degree range and the 120 to 180 range (and therefore the 180 to 240 and 310 to 360 range). The same study was done during the 2001 fishery, but no matches between observer reported positions and CFAR generated positions were made. The 2001 fishery took place during very high winds and seas, which most likely affected the results. In 2002, the conditions were milder, but differences between the three study days were still noted. The first two images, where all the detections took place had a wind speed of 4.5 m/s and sea state if .9 m, whereas the third image that had no detections had double the wind speed and seas state. The number of matches is still few, therefore necessitating further studies using many more matches to find significant results.

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